Freshwater Quality Monitoring Protocol
San Francisco Area Network

Standard Operating Procedure (SOP) # 8

FIELD AND LABORATORY METHODS FOR SEDIMENT

Version 1.01

August 2005

REVISION HISTORY LOG:

Prev. Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #
1.0	8/8/05	M. Cooprider	Minor edits, incorporated comments from technical reviewer	Preparation for formal peer review	1.01

Only changes in this SOP will be logged. "Version numbers increase incrementally by hundredths (e.g. version 1.01, version 1.02, …etc) for minor changes. Major revisions should be designated with the next whole number (e.g., version 2.0, 3.0, 4.0 …). Record the previous version number, date of revision, author of the revision, identify paragraphs and pages where changes are made, and the reason for making the changes along with the new version number" (Peitz et al, 2002).

Suggested Citation: Cooprider, MA. 2005. Field and laboratory methods for sampling sediment, Version 1.01, Standard Operating Procedure #8 . *In* San Francisco Bay Area Network Freshwater Quality Monitoring Protocol, Version 2.01, Appendix H-SOPs, National Park Service, San Francisco Bay Area Network, CA. 51 pp. Plus appendices.

TABLE OF CONTENTS

APPENDICES

A Sampling with the DH-48 Depth-Integrating Suspended Sediment Sampler
B Depth Integrated Sampling Data Sheet
C Turbidity Threshold Sampling Manual
D Laboratory Analysis of Suspended Sediment Concentration
Laboratory Analysis of Total Suspended Solids
E Turbidimeter Instrument Log

LIST OF ACRONYMS USED

APHA	American Public Health Association
DI	depth-integrated
DIW	deionized water
EWI	equal width increment
FISP	Federal Interagency Sedimentation Project
FTU	formazin turbidity unit
GOGA	Golden Gate National Recreation Area
I&M	Inventory and Monitoring
JOMU	John Muir National Historic Site
JTU	Jackson candle turbidity unit
LEW	left edge of water
NPS	National Park Service
NTU	nephelometric turbidity unit
PINN	Pinnacles National Monument
PORE	Point Reyes National Seashore
REW	right edge of water
RWQCB	Regional Water Quality Control Board
SFAN	San Francisco Bay Area Network
SOP	standard operating procedure
SSC	suspended sediment concentration
TMDL	total maximum daily load
TSS	total suspended solids
TTS	turbidity threshold sampling
USDA	United States Department of Agriculture
USGS	United States Geological Survey
USEPA	United States Environmental Protection Agency

1.0 SCOPE AND APPLICATION

The purpose of this standard operating procedure (SOP) is to provide detailed guidance on methods of sediment sampling in the water column and analysis of sediment samples for turbidity, total suspended solids, and suspended sediment concentration. This SOP also provides guidance on operation of a turbidity threshold sampling station. Sampling locations and frequencies for 10 watersheds in four National Park Service (NPS) units of the San Francisco Bay Area network (SFAN) are discussed.

1.1 Introduction

Sources of sediment in streams include erosion from stream banks, runoff from various source areas within a watershed, and re-suspension from the streambed during storm events. Some suspended solids can also originate from algal and bacterial growth. Sediments are deposited in areas where stream flow is slow. For example, gravel bars form along streambanks where flow is slower since a slower flow cannot transport as much sediment as high flows. Erosion and sedimentation are natural processes. However, agriculture and land development can accelerate these processes and result in an imbalance in the amount of sediment in a stream system.

The amount of sediment in water is quantified as milligrams per liter (mg/L) of total suspended solids (TSS). The method for determining TSS utilizes a sub-sample (100mL) of the overall sample. The method for determining suspended sediment concentration (SSC) is very similar to the TSS method except that the entire sample is used. Turbidity, another measurement of suspended sediment, is the capacity of suspended solids including clay, silt, finely divided organic and inorganic matter, soluble colored compounds, plankton, and microscopic organisms in water to scatter light (American Public Health Association et al., 1998). Turbidity is often measured in Nephelometric Turbidity Units (NTU). Other equivalent units that are used include Formazin Turbidity Units (FTU) and Jackson Candle Turbidity Units (JTU). High turbidity water can be described as cloudy or milky.

1.2 Sediment Impaired Waters Within SFAN

In 2000, the San Francisco Bay Regional Water Quality Control Board ("Regional Board") identified both Lagunitas Creek and Tomales Bay as impaired by sediment. These watersheds are located in western Marin County within Golden Gate National Recreation Area (GOGA) and Point Reyes National Seashore (PORE). San Francisquito Creek is also listed as sediment impaired. West Union Creek, a tributary of San Francisquito Creek in San Mateo County, flows through Phleger Estate in GOGA. The Regional Board has established a timeline for development of Total Maximum Daily Loads (TMDLs) associated with these impairment listings (Table 1).

Other watersheds within SFAN are negatively impacted by sediment but are not specifically listed but the Regional Board. One example is Strentzel Creek, partly located within John Muir National Historic Site (JOMU). Strentzel Creek is within the Alhambra Creek watershed in Contra-Costa County. Redwood Creek (GOGA) and other watersheds within SFAN also have sediment-related issues.

Table 1. San Francisco Bay Regional Water Quality Control Board TMDL Project Timeline as of 6-29-05

Water body	Park Unit	Pollutant	Project Report Completion	Regional Board Adoption Date
San Francisquito Creek	GOGA	Sediment	Dec. 2005	Dec. 2006
Lagunitas Creek	PORE, GOGA	Sediment	Dec. 2006	Feb. 2008
Tomales Bay	GOGA, PORE	Sediment	Dec. 2007	Dec. 2008

These streams are listed because of habitat degradation due to deposition of fine sediments and due to their significance in providing critical habitat for threatened and endangered anadromous fish in the Bay Area. Populations of steelhead, salmon, and other native aquatic species have declined in the past fifty years in Bay Area streams. Other problems associated with excess sediment are related to water supply and include high turbidity and filling in of reservoirs (San Francisco Bay Regional Water Quality Control Board, 2003).

An approach for developing sediment TMDLs in San Francisco Bay Area streams was developed by the Regional Board in 2003. The first step in developing sediment TMDLs is to determine what factors impact fish populations (e.g., lack of flow, too much sediment, and fish migration barriers). These analyses also help establish priorities for watershed assessment, management, and restoration. Where sediment is verified to be a limiting factor, a sediment budget study will be conducted in order to quantify sediment inputs and outputs in a stream. A sediment budget study seeks to identify all sources of sediment and quantitatively estimate the amount of sediment transport to streams (San Francisco Bay Regional Water Quality Control Board, 2003).

SFAN staff are coordinating with the Regional Board. At this time it is uncertain what requirements there will be for sediment monitoring in the Olema, Lagunitas, and West Union Creek watersheds in association with the Sediment TMDL. Point Reyes National Seashore has monitored TSS in Olema Creek since 2000. Monitoring for TSS in GOGA began as early as 1964 in some watersheds. SFAN also recently began water quality monitoring in West Union Creek, a tributary to San Francisquito Creek. In addition, in order to facilitate the development of a sediment TMDL for Tomales Bay and Lagunitas Creek, a Turbidity Threshold Sampling (TTS) unit was installed in Olema Creek, a tributary to Lagunitas Creek, in December 2002. This unit includes an automatic pump that collects water samples at a set of turbidity "thresholds" during a storm event. Samples are then analyzed for SSC. The turbidity, SSC, and water level data associated with the TTS station provide insights into the sediment transport dynamics within the creek.

1.3 Water Quality Criteria Recommendations for Sediment

Visible turbidity is considered to be greater than 5 NTU (Strausberg, 1983). Turbidities of 25 NTU or greater have caused reductions in juvenile salmonid growth (Sigler et al., 1984). The National Park Service Water Resources Division uses a "screening criteria" of 50 NTU to determine water quality exceedences in its Baseline Water Quality Inventory and Analysis Reports (National Park Service, 2003). More damage to fish and macroinvertebrates is probable if high turbidities remain in a stream system (Newcombe and MacDonald, 1991).

The UC Cooperative Extension Fact Sheet on Fishery Habitat provides a summary of the effects of varying turbidity and TSS concentrations on salmonids (Larsen, 1999; Lloyd, 1987). Juvenile and adult salmon experience moderate stress when exposed to more than six days of TSS greater than 10 mg/l or one day of exposure to TSS > 50 mg/L (Newcomb and Jensen, 1996). High TSS (> 300 mg/L; ~ >40 NTU) inhibits fish feeding, can clog fish gills and can cover gravel spawning-beds (Creek Connections, 2004; Horne, 2003). Table 2 summarizes recommended water quality criteria. Ecoregion II refers to the "Western Forested" Region that includes GOGA, MUWO, and PORE. Ecoregion III is the "Xeric West" that includes PINN and JOMU.

Table 2. Recommended criteria for sediment

	Sigler et al., 1984	**Newcomb and Jensen, 1996**	**EPA Aggregate Ecoregion II Criteria (2003)**	**EPA Aggregate Ecoregion III Criteria (2003)**
∗Acute Total Suspended Solids		> 50 mg/L		
∗Chronic (>6 days) Total Suspended Solids (TSS)		> 10 mg/L		
[ϕ]Turbidity	25 NTU		1.30 NTU	2.34 NTU

∗Total suspended solids are listed in milligrams per liter (mg/L)
[ϕ]Turbidity is listed as nephelometric turbidity units (NTU)

In streams, the most desirable algae species are the diatoms, the golden brown algae. The golden brown color of coastal California streams is due to a thin coating of diatoms on the rocks and cobble. These diatoms can move slowly and form a nutritious biofilm on the rocks that is a major food supply for valuable insect larvae such as mayflies, caddis flies and snails. Clear water with low TSS is vital since not only must sunlight reach the steam bed but sediment-laden water will scour the rocks killing the diatom biofilm (Stafford and Horne, 2004). Certain species of macroinvertebrates are also sensitive to changes in sediment. Maintaining streams with TSS levels low enough to support fish, algae and other aquatic life is a significant concern for SFAN.

1.4 Sediment Levels in SFAN Waters

Total suspended solids and turbidity have been measured in GOGA since 1964. At Pinnacles National Monument (PINN), TSS has been measured from 1997 to 2001, not including 1999. At PORE, TSS has been monitored since 1997. A summary of TSS and turbidity data is included in Tables 3 and 4.

Table 3. Total Suspended Solids in mg/L

	PORE	GOGA	PINN
Maximum	1281	8000	240
Median	0.8	23	< 5 mg/L (detection limit)
Mean	10.2	98	154
# of observations	465	614	10

Table 4. Turbidity in Nephelometric Turbidity Units (NTU)

	GOGA
Maximum	255, 270
Median	22.8
Mean	35.7

Note: Data is not currently available for PORE. PINN did not collect turbidity data. Data included in this table is from 1964 to 2002 from the GOGA database (up to 1999) and subsequent stables studies (2000-2001).

1.5 Sediment Monitoring Rationale & Objectives

1.5.1 Sediment Concentration and Turbidity Comparisons

Investigations regarding the comparability of TSS and SSC analytical results conclude that SSC and TSS collected from natural waters "are not comparable and should not be used interchange-ably" (Gray et. al., 2000). The methods for analyzing TSS and SSC are essentially the same except that SSC measurements are derived from the entire natural water sample while TSS samples are derived from a subsample (usually 100 ml of a 1 liter sample) of the natural water sample. Subsampling by either pipette or pouring from an open mouth bottle tends to produce a sand-deficient sample (Glysson et al., 2000). Therefore, TSS is typically slightly less than SSC (Glysson and Gray, 2002). Originally, TSS was developed as a proxy for SSC in wastewater samples. This comparability breaks down when conducted on natural water samples.

Turbidity is a measure of interference in the water column produced by both mineral and organic particles. Monitoring efforts in the northern coast of California show that at certain times, the organic component of the flow can account for 60 – 80% of the turbidity measured at a site (Madej et al., 2002). TSS and SSC do not include this organic component.

There is a range of literature available showing that TSS and turbidity information can be correlated resulting in well-established relationships (Packman et al., 2000; Lewis et al., 2002). The same cannot be done with SSC and turbidity (Glysson and Gray, 2002). While better correlation is found in samples with low sand content, there is a wide variability in these conditions between stations. While direct correlations between these parameters are problematic, the NPS proposes collection of TSS or SSC in addition to turbidity. Results of paired analysis (turbidity and either TSS or SSC) will be used to report results for each of the monitored stations.

1.5.2 Sediment Monitoring Questions

1. Is turbidity chronically high (how long does turbidity remain in a stream after the peak of a storm event)? *Justification: Chronic turbidity is more of a concern for fish then sediment spikes that are typical in winter storms in coastal California; fish find refuge during storms. This can also help determine whether management practices to reduce erosion are effective. In addition, data can be plotted with lines indicating various turbidity thresholds; see Section 1.3 of this SOP.*

2. Are the magnitudes of the winter spikes changing? *Justification: This helps assess the condition of the land and determine whether the sediment load is increasing or decreasing over time. This can also help determine whether management practices to reduce erosion are effective.*

3. What and where are the sources of sediment within the watersheds? *Justification: If problems are identified through questions #1 and #2, the sediment sources will need to be identified. Much sediment reduction work is conducted via geomorphology or other surveys and may not necessarily require water quality sampling for sediment. It is critical that park and network staff work together to identify sediment sources and discuss possible site locations for sediment monitoring if it is deemed necessary..*

4. Is there a significant relationship between turbidity and SSC during a storm event or at other times of the year? Justification: Once a relationship is established, turbidity can be used as the primary indicator of sediment water quality. Turbidity is a more simple and cost effective means of monitoring sediment.

Monitoring questions #2 and #4 require a turbidity threshold sampling station and therefore would only apply to Olema Creek. Monitoring question #3 may be beyond the scope of the I&M program but is included here since it is important for the parks. Monitoring as part of the freshwater quality protocol will focus on question #1. However, additional information related to questions #2, 3, and 4 is provided in this SOP as reference. Table 4 provides information about monitoring location and frequency for each of the sediment monitoring questions.

Table 4. Sediment monitoring questions, location, sampling frequency and analysis.

Monitoring Question	Watershed	Location	Frequency	Analysis
Chronic turbidity	All; in-situ sensor priority: Lagunitas, Olema, Redwood, Pine Gulch, West Union	All water quality monitoring sites, in-situ turbidity sensors at stream gauges if applicable	After storms and continuously (rotate the in-situ turbidity sensor to cover all watersheds)	Turbidity by turbidimeter and in-situ sensor; TSS
Magnitude of sediment spikes	All	At long-term water quality monitoring stations or fish index reaches	2-3 storm events each annually (must catch peak of storm event)	Turbidity, TSS, particle size
Sediment sources	As needed	Upstream and downstream of suspected sources	Storm events; coarse level erosion inventory	Turbidity, TSS
Turbidity vs. SSC	Olema	Bear Valley Rd. bridge, TTS station	As many winter storm events as possible	Turbidity by in-situ sensor, SSC

Watersheds to be monitored for chronic turbidity (question #1) include Lagunitas Creek, Olema Creek, Redwood Creek, Pine Gulch, West Union Creek, Strentzel Creek, Rodeo Creek, Tennessee Valley, Chalone Creek, and Franklin Creek. Water samples should be collected as soon as possible after a storm peak. Collect at least 1-2 samples near the peak, then daily until the water clears (Randy Klein, personal communication, 5 July 2005). Just 4-5 samples during the recessional limb of a hydrograph can be useful since this is when chronic turbidity occurs (Randy Klein, personal communication, 5 July 2005).

2.0 FIELD TECHNIQUES

2.1 Introduction

Sampling during storm events presents unique challenges in the San Francisco Bay Area. Winter weather is unpredictable with significant variation in rainfall quantity and distribution among and within the parks. Watersheds are small and stream stage and velocity can increase rapidly in a very short period. The I&M Freshwater Dynamics protocol will include measuring stream stage and velocity in order to create a hydrograph. The hydrograph is a very useful tool to predict stream flow. In planning sediment sampling events, it is important to be aware of impending weather conditions and to be familiar with each stream's hydrograph.

2.2 Preparations and Field Rinsing of Equipment

(Adapted from Radtke and Wilde, 2002)

Most equipment used for sample collection and processing is field rinsed with the water to be sampled just before the water samples are collected. The purposes of field rinsing are to condition, or equilibrate, the equipment to the sample environment and to help ensure that all cleaning solution residues have been removed before sampling begins.

To field rinse a surface-water sampler and sample bottle:

1. Put on appropriate disposable, powderless gloves.
2. Partially fill and rinse the sampler and bottle with the water to be sampled (rinse water). Avoid getting sand in the rinse water. If there is not a sufficient amount of sample water, use deionized water (DIW).
3. Shake vigorously to rinse. Discard the rinse water by swirling the solution out of the bottle or sampler. Swirl and then drain the rinse water from the sampler through the nozzle. Shake off adhering water droplets.

Equipment Checklist

Gloves
Bottles appropriate for DH 48 sampler
DH 48 wading sampler
Velocity meter
Tape measure/tag line
Chaining pins
Personal flotation device and other safety equipment
Watch
Data sheets/*Rite in the Rain*™ notebook

2.3 Isokinetic, Depth-Integrated Sampling

Since suspended sediment concentration varies from the water surface to the stream bed and laterally across a stream, depth integrated sampling will be utilized. This will help ensure that the entire water column of the stream is adequately represented. For depth-integrated sampling within SFAN, the equal-width-increment (EWI) method will be used. Consult the USGS National Field Manual for specific information regarding this method.

There are several different kinds of samplers used for depth-integrated sampling; SFAN uses the sampler model DH-48. For isokinetic sampling with a bottle sampler, the mean velocity of the vertical that is sampled must exceed 1.5 ft/s (Webb et al., 1999). In the sampling operation the intake nozzle is oriented into the current and held in a horizontal position while the sampler is lowered at a uniform rate from the water surface to the stream bottom and instantly reversed. The sampler continues to take its sample throughout the time of submergence. For detailed specifications, sampler assembly, and instructions for use of the DH-48 sampler see the Federal Interagency Sedimentation Project information on the DH-48 sampler ((FISP, 1958). This information can be found at http://fisp.wes.army.mil/Instructions%20US%20DH-48%20001010.PDF

Before field work, clean appropriate parts of the sampler and store in plastic for transport to the field site. All sampling equipment should be checked prior to heading out into the field. A clean sampling container and nozzle should be used for every sample. Refer to the pre-field check list for the D-48 isokinetic sampler in Table 5.

Table 5. Pre-field check list for D-48 hand-held samplers (adapted from the Federal Interagency Sedimentation Project (FISP, 1958) and Webb and Radtke, 1998, *Selection of Equipment for Collection of Water Samples*.

√	Sampler Items	Comment
	Sampler body	Inspect sampler body for damage and missing parts.
	Air exhaust port	Both ends should be clear and unobstructed to ensure inflow efficiency.
	Nozzle	The yellow nozzle should be straight with no visible signs of damage, check for damage to the threads on the nozzle; also inspect the bore for straightness and any signs of burrs or deformity. If damage or burrs are found in the bore or at either opening, it should be discarded and replaced with a new nozzle.
	Bottle gasket	If the gasket is hard to the touch torn, or will not fit flush in the gasket seat of the sampler, it should be discarded and replaced. If the gasket is in good condition, it should remain in place once it is pressed into the seat.
	Sampling container	Inspect the bottle for cracks and ensure that it is clean.
	Wading rod and extensions	Check for damage to screw threads.
	Mechanical Operation	Test the overall working condition of the sampler.
	Laboratory results from analysis of sampler blank	Make sure the sampler has been quality assured with an annual equipment blank and certified for water-quality use.
	Separate sets of sampler components and back-up components	If at all feasible, for a given field trip when collecting multiple water samples, prepare and use separate sets of sampler bottles, caps, and nozzles for each sampling site. Have backup equipment available on-site.
	Field-cleaning supplies and blank water	If separate sets of sampler components are not available, then clean equipment between sampling sites and be prepared to process the number of field blanks needed to document that equipment was adequately cleaned.

Preparation for sampling:

- Set up a tape measure or tag line across the stream, record the left edge of water (LEW), facing downstream, and the right edge of water (REW) and width (see data sheets in Appendix B).
- Obtain a discharge measurement noting the range in velocities across the channel. Consider whether the distribution of sediment will change during sample collection.
- Velocity must at least 1.5 ft/s but should not exceed 9.0 ft/s in order to collect an isokinetic sample with the DH-48 (Webb et al., 1999).
- When choosing a cross sectional width to sample, avoid side channel eddies. The depth-integrated sampler cannot be used where there is upstream eddy flow.
- Maximum safe wading depths depend on the size of the field technician, the stream velocity, and the streambed material. In general, do not attempt to wade a stream for which values of depth multiplied by velocity are greater than or equal to 10 ft^2/s. Caution should also be used if the stream depth is greater than 3 ft.
- Always wear a personal flotation device and be familiar with other safety procedures listed in SOP#2-Personnel Training and Safety.
- A rope deployed depth-integrated sampler such as the DH-59 can be utilized from a bridge during high flows where the wading sampler cannot be used. The DH-59 is recommended for high road bridges such as Bear Valley Rd. over Olema Creek, Hwy. 1 over Redwood Creek, and Hwy. 146 over Chalone Creek).
- Alternatively, for depths too deep to wade, the DH-48 has wading rod extensions in 3-ft lengths that can be added for use from a boat or low bridge (e.g., pedestrian trail bridges over Franklin Creek, Rodeo Creek, and Bear Gulch). With all extensions, the maximum sampling depth is 9 ft.
- A plastic 500mL sample bottle should be used for depth-integrated sampling. Ensure that the sampling bottle is not cracked.

Depth-integrated sampling technique: (*adapted from Webb et al., 1999*)

1) Divide the channel into 10-15 vertical panels (“increments”), no more than 20 depending on the width of the channel and the range in velocities. For a cross-sectional width of < 5 ft, use as many increments as practical, but equally spaced a minimum of 3 in. apart. For a width of > 5 ft use a minimum of 10 equal width increments.
2) Starting at the LEW, take a sample from the midpoint of each vertical into the same bottle.
3) Lower the sampler until slight contact is made with the streambed.
4) Do not pause upon contacting the streambed. Raise the sampler immediately at a constant transit rate to complete the vertical traverse. The descending transit rate does not have to equal the ascending transit rate, but each rate must be unidirectional and constant, until the sampler bottle is full.
5) Take care not to disturb the stream bed or disrupt flow (be aware of your location the stream)

6) Fill the bottle 75-90% full (approximately 375 to 420 mL). If the bottle becomes entirely full full, the sample should be discarded since it may not be representative (Federal Interagency Sedimentation Project

10) Note the stage height. If it is changing rapidly, move fast across the stream as you fill the bottle.

11) Dry the bottle and label each bottle with site location ID, date, time and initials of field crew. It is helpful to partially fill out the label before heading into the field.

12) Place the bottle in a cooler with blue ice and keep chilled at 4°C in the dark. Samples should be analyzed for SSC as soon as possible (within 24hrs), and should not be stored more than seven days. Turbidity measurements should be taken as soon as possible within 24 hrs. (American Public Health Association et al, 1998).

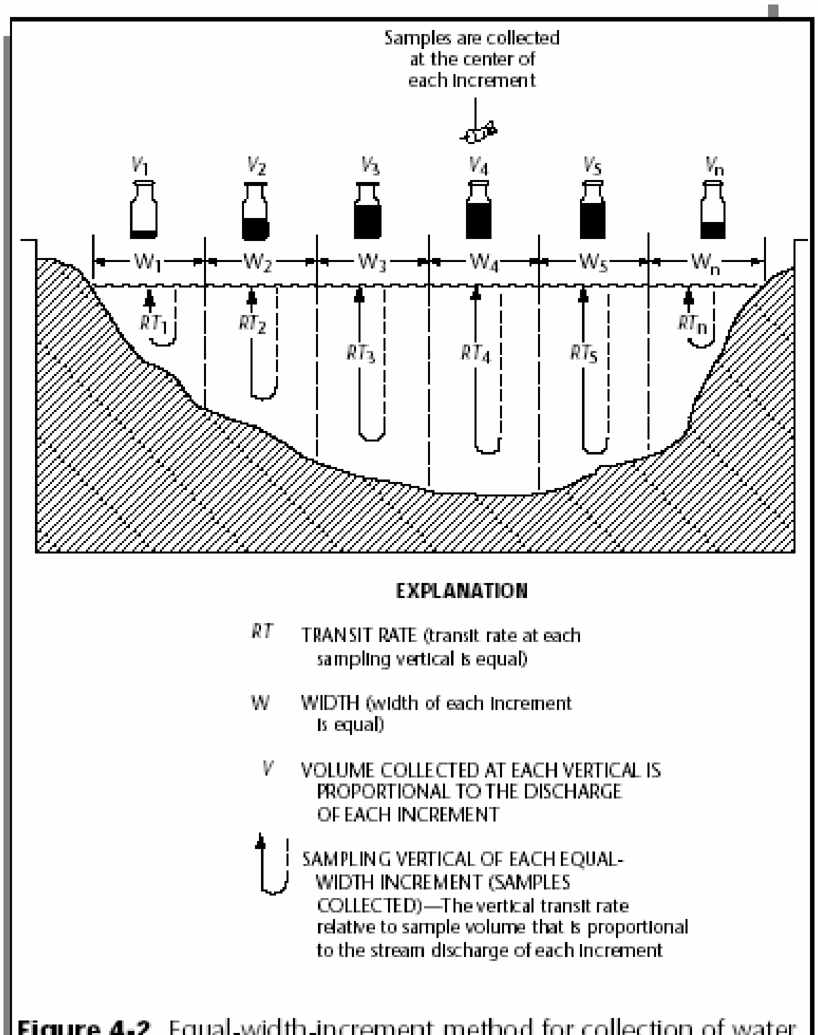

Figure 4-2. Equal-width-increment method for collection of water samples (modified from Edwards and Glysson, 1998).

Figure 1. From USGS National Field Manual (Webb and Radke, 1998)

2.4 Non-isokinetic Sampling

For isokinetic sampling with a bottle sampler, the mean velocity of the vertical that is sampled must exceed 1.5 ft/s. If this minimum velocity is not met, collect grab samples using an open mouth sampler at the centroid of flow approximately 12 inches below the water surface, if possible. The hand-held bottle sampler is the simplest type of open-mouth sampler. A bottle is dipped to collect a sample where depth and velocity are less than the minimum requirements for depth-integrating samplers.

2.5 Turbidity Threshold Sampling

Due to the status of Lagunitas Creek and Tomales Bay as sediment-impaired waters, Olema Creek, a tributary to Lagunitas Creek, was chosen as a location to conduct turbidity threshold sampling (TTS). As part of this pilot project, Point Reyes National Seashore contracted with Graham Matthews & Associates to perform the installation of the TTS unit and to provide training for operation of the TTS unit. In December 2002, the TTS unit was installed at the Olema Creek stream gauge at the Bear Valley Road Bridge near the park headquarters. Over the past few years, the consultant has made numerous system modifications and park staff have been learning the operation and maintenance of the system. The system was fully functional in May 2003.

2.5.1 Introduction

Turbidity threshold sampling involves methodology and instrumentation developed by the U.S. Department of Agriculture (USDA), Forest Service, Redwood Sciences Laboratory (Lewis,1996; Lewis and Eads, 1996; Eads and Lewis, 2002; Lewis, J., R. Eads, and N. Cambell-Lund, 2002). The TTS procedure involves collecting water samples that are distributed over a range of rising and falling sediment concentrations in a stream. The data resulting from TTS can be used to determine suspended sediment loads by establishing a relationship between sediment concentration and turbidity. A general description of turbidity threshold sampling was written by Rand Eads (2001) and is included below. The document with photos of TTS station components can be found at http://www.fs.fed.us/psw/topics/water/tts/tts_inst.shtml .

> **The Importance of Automated Data Collection:**
>
> The ability to collect useful information about suspended sediment transport and water discharge is dependent on the timing and frequency of data collection during storms. All river systems, particularly smaller watersheds that respond very quickly to rainfall, benefit from automated data collection. In rain dominated regions most suspended sediment is transported during a small number of events. Although it is possible to rely solely on manual measurements, important storm flows are usually infrequent and difficult to predict. When they do occur, trained personnel may not be available to collect the required information. Infrequent, systematic manual sampling will not provide adequate information to make credible suspended sediment load estimates under these conditions. As of yet, there is no reliable method to directly measure suspended sediment concentration in the field. Usually water discharge is not a good predictor of sediment concentration for rivers and streams that transport the bulk of their sediment load as fines

because the delivery of sediment to the channel from hillslopes, roads, and landslides is highly variable. For rivers that transport mostly sand, water discharge and concentration may be more closely coupled if transport depends mainly on stream power to mobilize in-channel sources that are not easily flushed from the system. However, in streams transporting fine sediment, a sampling scheme that employs a parameter such as turbidity, that is well correlated to suspended sediment concentration, can be expected to improve sampling efficiency and load estimation. Turbidity threshold sampling collects physical samples that are distributed over a range of rising and falling turbidities (Lewis and Eads: 1996, 1998 and 2000). The resulting set of samples can be used to accurately determine suspended sediment loads by establishing a relationship between sediment concentration and turbidity for any sampled period and applying it to the continuous turbidity data.

How Turbidity Threshold Sampling Works:

Turbidity is an optical measure of the number, size, shape, and color of particles in suspension. A number of manufacturers offer turbidity probes that can be deployed on a continuous basis in streams. The optical properties of sediment, mainly size and shape, have a large influence on the magnitude of the turbidity signal. For instance, sand particles return a much lower turbidity signal for a given concentration than silt and clay particles of the same concentration. TTS utilizes turbidity thresholds, points at which physical samples are collected, distributed across the entire range of expected rising and falling turbidities. Contamination of turbidity probe's optics by debris, algae, or macroinvertebrates can lead to a noisy, or progressively increasing, turbidity signal. Sensors with reliable optical wipers, such as the DTS-12, manufactured by FTS, can reduce optical fouling and are recommended to improve data quality. Careful design of the turbidity probe's housing and mounting hardware can reduce fouling from large organic debris.

Turbidity thresholds are selected by taking into consideration the maximum expected turbidity value for a stream, the range of the turbidity probe, and the number of desired physical samples based on the magnitude of the storm. In our experience, using a square-root scale to distribute the thresholds provides an adequate pairing of turbidity-concentrations to produce acceptable regressions. For the smallest storms, three or four samples should be adequate, while large events may produce 5 to 15 samples. Different sets of thresholds are used when turbidity is rising and falling, with more thresholds required during the much more prolonged falling period. The user can fine-tune the distribution of thresholds to maximize efficiency. A set of rules, in addition to the predefined turbidity thresholds, aids in reducing sampling during short duration turbidity spikes, ensures that a "startup" sample is collected at the beginning of a storm, and defines reversals in turbidity. The rules permit continued sampling when turbidity levels exceed the turbidity probe's range, and they allow collection of non-threshold, manually triggered samples to be paired with depth-integrated samples or to augment sample numbers if desired.

Closely spaced turbidity measurements produce interesting trends in sediment transport such as spikes superimposed on the storm turbidigraph that often indicate landslides or streambank failures upstream. In the case of nested watersheds, the timing and magnitude of these sediment pulses may provide additional information about cumulative effects, or dilution, downstream. Authenticity of these turbidity spikes is confirmed when physical samples taken during the spikes have higher concentrations than surrounding samples.

Instrumentation:

Data Logger and Sampling Logic

A programmable data logger is required to make the required sampling decisions. For remote locations, it is important that the data logger has low power requirements in order to preserve the battery's capacity. The TTS program only requires input information about stage and turbidity to decide what actions to take. Wake-up intervals are either set at 10-minutes for small, flashy watersheds, or at 15-minute intervals for larger basins. At the beginning of each wake-up interval, the OBS-3 turbidity probe, under control of the program logic, collects 60 measurements in 30 seconds (mention of product names is not an endorsement by the USDA Forest Service). Next, the raw turbidity values are sorted and the median value is determined. We have found that these two operations effectively reduce outlier values. In the case of the DTS-12, the sampling frequency and period, and reported statistics, are controlled by the sensor's onboard processor. The program next collects 150 stage readings in three seconds from a pressure transducer and computes the mean stage. The mean stage is then compared against the minimum operating stage to determine if the turbidity probe and sampler intake are adequately submerged (stage is above "baseflow") to allow sampling. If the program logic determines that a sample is required, based on the rules discussed above, it activates an automatic water sampler to collect one sample. Other instruments, such as tipping bucket rain gages and water temperature probes, may be connected to the data logger to provide additional information. Finally, all pertinent records are written to data logger memory. The TTS logic, discussed above, has been developed for Campbell data loggers. The TTS program is executed from the Campbell CR10X data logger platform

Turbidity Probe

The OBS-3 turbidity probe, manufactured by D&A Instrument Company, is a backscatter nephelometer that emits infrared radiation (IR) into the water column. The distance the IR penetrates the water depends on the probe's optical configuration and the amount and type of sediment in suspension. The penetration, or volume sampled, decreases with increasing concentration of material. The scattered IR returned to the sensor's detector is a function of particle size and shape and the number of particles in suspension. Comparisons made with different turbidimeters should be viewed with some skepticism due to inconsistencies in light sources, calibrations, and the sampled volume. Periodic calibration of the turbidity sensor in formazin standards is required to compensate for instrument drift and scratched optical surfaces. Sensors with a small viewing area (1 cm or less) reduce the chance that large debris will be viewed by the optics and allow for shallow deployment. Small viewing areas often do not provide adequate sampling volume and may produce noisy data. Large viewing areas (7 to 25 cm) have the opposite characteristics. A viewing area of 4 to 7 cm is a good choice.

The turbidity probe housing reduces contamination from organics by shedding debris. The housing, if properly designed, can reduce hydrodynamic noise caused by turbulence and the entrainment of air or re-suspension of sediment close to the sensor. The housing also protects the sensor from direct impacts by large submerged organic debris.

Note: The DTS-12 turbidity sensor is now more commonly used, is the recommended sensor, and is self-cleaning (Randy Klein, personal communication, 7 July 1005).

Sampling Boom

The boom positions the turbidity probe and sampler intake at the appropriate position and depth in the stream. Since the boom is articulated, large floating organic debris can, on impact, lift the vertical arm of the boom to the surface and pass underneath. Increasing water velocity and depth pushes the vertical boom arm downstream, raising the turbidity sensor higher in the water column. A counterweight prevents the boom from rising to the water surface. The highest probability of contamination by organics, and resulting loss of data, occurs during flood stages when organic material is recruited from flood plains. A bank-, cable-, or bridge-mounted retrievable boom is desirable for all but the smallest streams to allow debris removal during high flows. The depth of the turbidity probe can be adjusted as needed to position the probe above the zone of bedload transport and below the water surface. Changing the depth of the turbidity probe can change the ratio of coarse and fine particles sampled by both the turbidity probe and sampler intake.

-By Rand Eads, Redwood Sciences Laboratory, 2001.

TTS is a high level of monitoring and is very intensive in terms of maintenance/troubleshooting and the number of samples that are collected. For example, 200 samples could be collected during a few storm events. A significant amount of time is also required to correct turbidity data. For other streams besides Olema, a lower level of monitoring can be just as effective. For a turbidity threshold sampling station, instead of fixing on one turbidity threshold as a standard, it is useful to determine the number of hours that turbidity exceeded various thresholds such as 25, 50, 100, 200, 500, and 2000 NTU ((Randy Klein, personal communication, 7 July 2005).

Without a TTS unit it is difficult to capture the peak of a storm event. A useful alternative is to take samples during the recessional limb of a storm since this is where chronic turbidity occurs. Even four to five samples can provide enough points to create a recessional turbidity curve. Four to five samples from four storm events can provide enough points to have an overlay that fits well over the curve produced from 200+ samples collected by the Isco automatic sampler. Overlaying these curves on each other also allows you to see the point at which watershed size and geology affects on the curve disappear. Focus on taking 1-2 samples immediately after the storm peak then one every day until the water clears. Favor more samples closer to the peak (Randy Klein, personal communication, 7 July 2005).

2.5.2 TTS Program

The Turbidity Threshold Sampling Program for the CR10X datalogger contains all of the program information including turbidity threshold codes, sample codes, subroutines, pressure transducer and turbidity sensor wiring and connections and other electronic aspects of the program (Lewis et al., 2002). The program "wakes-up" and records measurements every 10 minutes at the Olema TTS station. The OBS-3 sensor measures turbidity at 0.5 second intervals for 30 seconds for a total of 60 readings. The median turbidity of these readings is then saved. The median turbidity and average stage values are used to trigger a pumping sampling if the sampling criteria are satisfied (Lewis et al., 2002).

Detailed instructions on programming the data logger, initializing a new station, connecting to an existing station, and retrieving data from a TTS station are included in the TTS Field Manual in Appendix C.

2.5.3 Summary of Field Tasks and Data Analysis for TTS

1. Check the station weekly and during every storm event (see Table 6)
2. Troubleshoot station instrumentation as needed
3. Calibrate turbidity
4. Calibrate sediment concentration using depth integrated (DI) sampling during a storm event
5. Conduct laboratory and data analysis including:
    - Conduct laboratory analysis for SSC
    - Develop a standard procedure for data management
    - Develop turbidity - sediment rating curve (TTS rating curve)
    - Plot DI sample turbidity against ISCO sampler turbidity
    - Plot DI sample SSC against ISCO sample SSC

Table 6. TTS Weekly Field Visits (complete these tasks in the order listed)

Observer Record	In the yellow "Rite in the Rain" ® station notebook record the following: ▪ Date, time, observer initials, battery IDs ▪ Presence of sediment, debris, or obstructions affecting turbidity probe. Wait until after data collection to correct problems ▪ View Left, Right, and Inside State
Check the ISCO Sampler	▪ Note the "next sample" value displayed by ISCO ▪ If > 2 minutes until a wakeup, inspect samples ▪ If volumes are too low* or high, see "Troubleshooting" in the TTS field manual (Appendix C)
Interrogate the data logger	▪ Launch the PC208Q software and connect to data logger. ▪ View and record the current values in the numeric window. ▪ Staff plate reading must be verified within 5 minutes of data record on display in numeric window
Optional: collect a DI or AUX sample	▪ Set appropriate sample flag ▪ Collect the sample at the next wakeup ▪ Update your record of staff plate readings and current values shown in the numeric window

Table 6. TTS Weekly Field Visits (continued)

Retrieve Data	▪ Choose between a "snapshot" data check and a Data Dump ▪ If dumping, set Dump Flag. (Confirm staff plate reading). ▪ Collect data, then dISCOnnect from data logger and exit PC208 W program.
Service turbidity probe	▪ Remove debris and sediment from housing, mounting apparatus, etc. ▪ Inspect/remove debris from inside housing. ▪ During non-storms, clean optics if necessary
Service flume or weir or rated section (section with hydrologic rating curve)	▪ Clear branches and debris ▪ Shovel sediment deposits downstrream through flume. ▪ Flush stilling well intakes if needed. ▪ Record changes in staff plate readings.
ISCO Sampler	Only if data is dumped, change ISCO bottles and reset distributor arm
System batteries	Replace low Gel cell battery only after confirming 9V > 9.0 volts
Dessicants	Check/replace dessicants
Additional Tasks	▪ See maintenance schedule ▪ Troubleshoot suspect equipment
Plot the data	▪ Run R_FieldPlot to graph the data
Complete the electronic field form	Run the Corel Database program to create an electronic field form incorporating your comments from the station notebook.

*ISCO sample bottles are 1000mL, the minimum sample volume for SSC analysis is 350 mL.

2.5.4. Calibrating the TTS Station

The USGS protocol for wading vs. bridge sampling is when the velocity x depth is $\geq$ 10, then use a rope deployed sampler (DH 59) for DI sampling from a bridge. Otherwise, use common sense to determine when to use the DH 48 wading sampler. Calibration should be conducted during a storm event in order to capture a large range of turbidities. Ideally, the DI sample would be taken during the largest storm event in order to have the most turbidity thresholds (all thresholds that would occur for that particular stream). The TTS station needs to be calibrated several times at different stages in the hydrograph. Depth-integrated sampling needs to be done for each new turbidity threshold so that a rating curve can be developed. DI samples represent the cross-sectional average sediment concentration and are used as "truth" to correct the TTS station ISCO pumped samples that are not flow-weighted but are point samples. The DI sample field data sheet is in Appendix B.

Sediment Calibration

1) Set up a tape measure across the stream, record LEW and REW, and width.
2) Measure the range in velocities across the channel.
3) See Section 2.3 for details on collecting a depth-integrated sample.
4) Divide the channel into 10-15 panels (no more than 20) depending on with of channel and range in velocities.
5) Download datalogger ("collect all" on PC208W program).
6) Follow page 10 of the TTS Field Manual "Collecting a DI Sample".

7) Collect the DI sample at approximately the same time as the ISCO sampler. You want to be halfway through your DI sampling when the ISCO pumps. The Olema Creek gauge at the Bear Valley Road bridge takes 35 seconds to start the rinse. It finishes pumping after 2 minutes and 20 seconds.
8) Collect several samples during the storm as long as it is safe to do so.
9) Conduct laboratory analysis for SSC on the DI samples and the ISCO samples following Section 3.1 in this SOP.

Turbidity calibration

Calibrate turbidity once a month. The turbidity probe should be approximately five inches below the water surface or at 50% of the depth. Collect a grab sample immediately downstream of the turbidity probe. Insert the sample bottle facing down and then turn horizontally so that the mouth of the bottle is facing upstream. Compare the field turbidity meter (e.g., Hach 2100P) reading with the turbidity probe reading. Consult the OBS-3 instruction manual for specific information about the turbidity probe (D&A Instrument Company, 2001). See Section 3.2.1 of this SOP and the Hach manual for detailed instructions on the Hach 2100P turbidimeter (Hach, 2001).

3.0 SAMPLE PRESERVATION, STORAGE, AND ANALYSIS

3.1 Suspended Sediment Concentration (SSC) and Total Suspended Solids (TSS)

Samples should be analyzed for suspended sediment concentration or total suspended solids as soon as possible (within 24hrs) and should not be stored more than seven days. The laboratory method for analyzing SSC is included in Appendix D. The TSS method follows the American Public Health Association (APHA) method (APHA et al., 1998). Laboratory analysis for SSC will be conducted at a certified laboratory. Analysis for TSS will be conducted either at a certified lab or at the GOGA wet lab. The SFAN water quality specialist and other trained staff will conduct the analyses. However, due to staff time constraints with the 7 day holding time and the need to sample during storm events, it may be necessary to have an outside laboratory analyze the samples.

3.2 Turbidity

Turbidity is time sensitive, so measurements should be obtained in the field. Biodegradation, settling, or sorption of particulates in a sample or precipitation of humic acids and minerals can affect the turbidity.

3.2.1 Turbidimetric Determination Using a Cuvette-Based Turbidimeter

It is highly recommend that program staff read the USGS National Field Manual Chapter section on Turbidity (Anderson, 2004). The following information about equipment calibration and maintenance is taken from both the National Field Manual and the Hach 2100P turbidimeter equipment manual (Hach, 200l).

Equipment and supplies:
Turbidimeter
Turbidity stock solutions and standards
    Formazin stock suspension (StablCal ®)
    Manufacturer provided secondary turbidity standards (Gelex ®)
Sample cells (10 mL cuvettes), clear colorless glass
Sample bottle (preferably one that does not adsorb suspended sediment; use an amber glass bottle if the sample is to be stored temporarily.
Silicon oil, optical grade
Paper tissues, extra lint free
Disposable gloves
Deionized water for rinsing
Non-phosporus detergent for cleaning sample cells
#2 single-hole stopper and syringe for degassing samples

Maintenance & Calibration of the Turbidimeter (see also Anderson, 2004 and Hach Instrument Manual, 2001)

- Protect instruments from extreme temperatures.
- Shield the instrument from direct sunlight.
- Check and replace batteries regularly.
- Follow the Hach manual for specific calibration procedures and preparation of formazin standards.
- Formazin standards are affected by temperature. To avoid the affects of temperature changes on the calibration, perform the Formazin and the secondary standard calibration at room temperature in the lab. Use three calibration standards that bracket the anticipated range of turbidity.
- Conduct instrument checks against the secondary standards in the field.
- Use the Gelex® standards for instrument verification only, not for calibration
- Periodically check two turbidimeters against each other.
- Discard turbidity standards that have expired and never pour used standard solution back into a stock container.
- Keep sample cells clean inside and out.
- Wash sample cells with non-phosphate detergent between each use and rinse with deionized water so that all detergent is removed.
- Let cells air dry in a dust-free environment.

Collecting Samples for Turbidity Measurement

- Turbidity measurements can be taken from either a grab-sample at the centroid of flow, from a pumped sample (ISCO sampler), or from a depth-integrated (discharge-weighted) sample.
- Turbidity measurements should be made in the field whenever possible. If it is necessary to store samples, the holding time should not exceed 24hrs (ASTM International, 2003a). Samples should be stored at $\leq$ 4°C to prevent biodegradation of solids.

Obtaining Turbidity Measurements:

- Shake the sample bottle vigorously to disperse all of the solids.
- Pour the sample into a sample cell to the line marked on the neck. Do not touch the cell walls with fingers.
- Remove air bubbles by degassing via vacuum produced using the stopper and syringe apparatus (see USGS National Field Manual, Anderson, 2004).
- Remove condensation from the cell with a clean, soft lint-free cloth or tissue.
- Apply a thin coat of silicon oil on the outside of the cell about every third time the cell is wiped free of moisture. The oil will mask minor imperfections and scratches; too much oil will attract dirt and could foul the cell compartment.
- Be sure that the sample is correctly oriented. Insert the sample cell so that the arrow on the cell faces the notch on the turbidimeter sample cell chamber.
- Press the "read" button to obtain a turbidity reading.

● Turbidity readings can be affected by unmatched cell orientation, condensation, gas bubbles, fingerprints, scratches, or dirt on the surfaces of the sample cell or turbidity probe.
● Avoid trying to run extremely high color or organic matter samples or else dilute. Otherwise the sample may be over range.
● Use in low light.
● Use on a level surface to help avoid stray light entering the measurement chamber.

Reporting Turbidity
● Turbidimeter specifications to include in the NPSTORET database are provided in Table 7 .
● Guidelines for reporting turbidity measurements are included in the Table 8.

Table 7. Hach 2100P Turbidimeter Specifications

Resolution	Measurement Range	% Difference from NTU Standards
0.01 NTU	<10 to 1,000 NTU	-5%, 20, to 950 NTU

Table 8. From USGS National Field Manual, Section 6.7 (Anderson, 2004)

Table 6.7–6. Guidelines for reporting turbidity units

[For ASTM and USGS measurements, refer to table 6.7–3 for reporting units based on instrument design. **Abbreviations:** USGS, U.S. Geological Survey; ASTM, ASTM International; EPA 180.1, U.S. Environmental Protection Agency method 180.1 (1993); GLI, Great Lakes Instruments; ISO 7027, International Organization for Standardization method 7027 (1999); NTU, nephelometric turbidity units; FNMU, Formazin Nephelometric Multibeam Units; FNU, Formazin Nephelometric Units; N/A, not applicable;<, less than; ≥, equal to or greater than]

Turbidity Reading	USGS	ASTM	EPA 180.1 (NTU)	GLI Method 2 (FNMU)	ISO 7027 (FNU)
0–<1	0.05	0.05	0.05	0.05	0.01
1–<10	.1	.1	.1	.1	.1
10–<40	1	1	1	1	1
40–<100	1	1	5	5	N/A
100–<400	10	10	10	10	N/A
400–<1,000	10	10	50	50	N/A
≥1,000	50	50	100	100	N/A

3.2.2 In-Situ Turbidity Sensor

An OBS turbidity sensor is currently included with the turbidity threshold sampling station on Olema Creek. Additional sensors will be purchased as funding allows. These sensors would bed rotated from watershed to watershed annually and would be used in conjunction with sampling for suspended sediment concentration. See the OBS instruction manual from D&A Instrument

Company for wiring, configuration, calibration and other specific features and tasks (D&A Instrument Company, 2001).

4.0 QUALITY ASSURANCE/QUALITY CONTROL

Field and laboratory duplicates are required. Analyze at least 10% of the sediment samples in duplicate. Duplicate determinations should agree within 5% of their average weight (American Public Health Association et al., 1998). Field and lab blanks are also required. See the SFAN Quality Assurance Project Plan, SOP#4, for more details.

5.0 REFERENCES

American Public Health Association, American Water Works Association, and Water Environment Federation. 1998. Standard methods for the examination of water and wastewater (18th ed.), pp. p. 2-8 to 2-11, American Public Health Association, Washington, D.C.

Anderson, C.W. August 2004. Turbidity: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6, section 6.7 accessed June15, 2005 from http://water.usgs.gov/owq/FieldManual/Chapter6/6.7_contents.html

ASTM International. 2003. D-1889-00Standard test method for turbidity of water, *In* ASTM International, Annual Book of ASTM Standards, Water and Environmental Technology, 2003, v. 11.01, West Conshohocken, PA. 6 p.

Creek Connections (2004): *Turbidity Information Sheet*. Creek Connections: Allegheny College. Accessed March 25, 2004 at http://creekconnections.allegheny.edu/Chemistry/TurbidityMain.html

D&A Instrument Company. 2001. Instruction Manual for OBS-1 & 3 Suspended Solids and Turbidity Monitor. Port Townsend, Washington. 41 pp.

Eads, R. 2001. Turbidity Threshold Sampling. Redwood Sciences Laboratory, U.S. Department of Agriculture, Forest Service. Arcata, CA. http://www.fs.fed.us/psw/topics/water/tts/tts_inst.shtml

Eads, R. and J. Lewis. 2002. Continuous turbidity monitoring in streams of Northwestern California. *In:* Turbidity and other sediment surrogates workshop (ed. by G.D. Glysson & J.R. Gray). 30 April - 02 May 2002, Reno, Nevada. 3 p.

Federal Interagency Sedimentation Project. 1958. Operating instructions for US DH-48 suspended-sediment hand sampler--Interagency Report J: Minneapolis, Minnesota, St. Anthony Falls Hydraulics Laboratory, 5 p. Accessed June 9, 2005 from http://www.fisp.wes.army.mil

Glysson, G.D. and J.R. Gray. 2002. Total suspended solids data for use in sediment studies. *Turbidity and Other Sediment Surrogates Workshop*, April 30-May 2, Reno, NV.

Glysson, G.D., J.R. Gray, and L.M. Conge, 2000. Adjustment of Total Suspended Solids Data for Use in Sediment Studies," in the Proceeding of the ASCE's 2000 Joint Conference on Water Resources Engineering and Water Resources Planning and Management, July 30-August 2, 2000, Minneapolis, MN, 10 p.

Gray, J.R, G.D. Glysson, L.M. Turcios, and G.E. Schwarz. 2000. Comparability of suspended-sediment concentration and total suspended solids data. U.S. Geological Survey, Water-Resources Iinvestigations Report 00-4191, Reston, Virginia.

Hach Company. 2001. Model 2100P Portable Turbidimeter Instrument and Procedure Manual. Loveland, Colorado. 76 pp.

Horne, A. J. (2003): Personal Communication, In S. Stafford (Ed.), Berkeley, CA.

International Organization for Standardization, 1999, Water quality — determination of turbidity: Geneva, Switzerland, International Organization for Standardization, ISO 7027, 10 p.

Larsen, R., E. (1999): *Fact Sheet No. 28: Fishery Habitat: 3) Sediment and Pollutants*. UC Davis, University of California Cooperative Extension. Accessed March 25, 2004 at http://danr.ucop.edu/uccelr/h28.htm

Lewis, D.J., K.W. Tate, R.A. Dahlgren, and J. Newell. 2002. Turbidity and total suspended solid concentration dynamics in streamflow from California oak woodland watersheds. USDA Forest Service Gen. Tech. Rep. PSW-GTR-184. 2

Lewis, J. 1996. Turbidity-controlled suspended sediment sampling for runoff-event load estimation. Water Resour. Res. 32(7): 2299-2310.

Lewis, J., and R. Eads. 1996. Turbidity-controlled suspended sediment sampling. Watershed Management Council Newsletter 6(4): 1&4-5.

Lewis, J. and R. Eads. 1998. Automatic Real-Time Control of Suspended Sediment Sampling Based Upon High Frequency in situ Measurements of Nephelometric Turbidity. *Proceedings of the Federal Interagency Workshop, Sediment Technology for the 21'st Century*, St. Petersburg, FL, February 17-19, 1998.

Lewis, J. and R. Eads. 2001. Turbidity Threshold Sampling For Suspended Sediment Load Estimation. *Proceedings Of The Seventh Federal Interagency Sedimentation Conference,* March 25- 29, 2001, Reno, Nevada.

Lewis, J., R. Eads, and N. Cambell-Lund. 2002. Turbidity Threshold Sampling Program. Redwood Sciences Laboratory, U.S. Department of Agriculture, Forest Service. Arcata, CA.

Lloyd, D. S. (1987): Turbidity as a water quality standard for salmonid habitats in Alaska. *North American Journal of Fisheries Management* **7**, 34-35.

Madej, M.A., M. Wilzbach, K. Cummins, C. Ellis, and S. Hadden. 2002. The contribution of suspended organic sediments to turbidity and sediment flux. *Turbidity and Other Sediment Surrogates Workshop*, April 30-May 2, Reno, NV.

National Park Service. 2003. Baseline Water Quality Data Inventory and Analysis, Point Reyes National Seashore. Water Resources Division. Technical Report NPS/NRWRD/NRTR-2000/280.

Newcombe, C. P. and J. O. Jensen. 1996. Channel suspended sediment and fisheries: a synthesis for quantitative assessment of risk and impact. No Amer. Fisheries Man 16 (4):693-719).

Newcombe, C.P. and D.D. MacDonald. 1991. Effects of Suspended Sediments on Aquatic Ecosystems. North American Journal of Fisheries Management. 11: 72-82.

Packman, J.J., K.J. Comings, and D.B. Booth. 2000. Using turbidity to determine total suspended solids in urbanizing streams in the Puget Lowlands. College of Forest Resources, University of Washington, Seattle, WA.

Peitz, D.G., S. G. Fancy, L. P. Thomas, and B. Witcher. 2002. Bird monitoring protocol for Agate Fossil Beds National Monument, Nebraska and Tallgrass Prairie National Preserve, Kansas. Prairie Cluster prototype monitoring program. Version 1.00, September 6, 2002

Radtke, D.B. and F.W. Wilde. 2002. General Information. U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A5, accessed June 29, 2005 from http://water.usgs.gov/owq/FieldManual/chapter5/pdf/generalinfor.pdf

San Francisco Bay Regional Water Quality Control Board, San FrancISCO Bay Region. 1995. Water Quality Control Plan – San FrancISCO Bay Basin (Region 2).
San Francisco Bay Regional Water Quality Control Board. 2003. Conceptual Approach for Development Sediment TMDLs for San FrancISCO Bay Area Streams. Oakland, CA.
Sigler, J.W., T.C. Bjornn and F.H. Everest. 1984. Effects of Chronic Turbidity on Density of Steelheads and Coho Salmon. Transactions of the American Fisheries Society, 113: 142-150.
Stafford, S. and A. Horne. 2004. A review of the water quality monitoring programs in the National Parks in central coastal California. Report to the National Park Service. University of California, Berkeley.
Strausberg, S. I. (1983): Turbidity interferes with accuracy in heavy metal concentrations. *Industrial Wastes* 29, 16-21.
U.S. Environmental Protection Agency, 1993, Methods for the determination of inorganic substances in environmental samples: Cincinatti, Ohio,U.S. Environmental Protection Agency EPA/600/R–93/100, 178 p.
U.S. Environmental Protection Agency, 1999, Guidance manual for Agency, Office of Water, EPA 815-R-99-010, variously paged.
Webb, W.E., D.B. Radtke, and R.T. Iwatsubo. September 1999. Surface Water Sampling: Collection Methods at Flowing-Water and Still-Water Sites. U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A4, accessed June 6, 2005 from http://water.usgs.gov/owq/FieldManual/chapter4/html/Ch4_contents.html
Webb, W.E. and D.B. Radke. 1998. Collection of Water Samples. U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A4, accessed June 6, 2005 from http://water.usgs.gov/owq/FieldManual/chapter4/html/Ch4_contents.html

APPENDIX A

Sampling with the US DH-48 Depth-Integrating Suspended-Sediment Sampler

http://fisp.wes.army.mil/Instructions%20US%20DH-48%20001010.PDF

APPENDIX B

Depth Integrated Sampling Form

Stream Flow Measurement Field Form

Depth Integrated (DI) Sampling for Sediment Calibration of Turbidity Threshold Sampling Station

Date: _________________

Site ID: _________________

Personnel: ____________

Stream section/location: ____

Flow (velocity): ________________

LEW: ______ft

REW: _____ft

Stream Width: _____ ft

BT (being time): ______

ET (end time): _____

BSH (beginning stage height): _____

ESH (ending stage height): _____

Bottles: _____

# of verticals (# of times in the water):______________

Panel size: _________

Type of sample (DI or AUX): ______

Equipment: DH 48 or other_____________

Pass: ______

Weather: ____

ISCO bottle #: _______

ISCO sample time: ________

Notes:

Date: **Time:**
Site ID: **Location:**
Field Conditions:

Station (ft)	**Depth (ft)**	**Velocity (ft/s)**	**Average V**
REW:			
LEW:			

Begin Time:
End Time:
Gauge height:

<u>Notes from USGS Flow Measurement Methods (See also the USGS protocol "Methods for Stream Discharge"):</u>

- For shallow depths, use 6/10 method
- For deep depths (> 1.5 ft) use the 2/10 and 8/10 method
  To get 2/10 depth multiply 6/10 depth by 2
  To get 8/10 depth divide 6/10 depth by 2
- Space the verticals so that no sub-section has more than 10% (ideally 5%) of the discharge
- There should be 20-30 sub-sections
- Keep the first sub-section as small as possible (depth will often be zero and assume no flow)
- Parts of the stream cross-sections with greater depth and velocity should have closer verticals
- Face the bank while taking measurement (stand beside not behind wading rod)
- Position yourself at least 18" from the wading rod
- Measure velocity for at least 40 seconds
- Check the meter during measurement
- Have an idea what the discharge will be before measurement
- Read gauge height after measurement
- Reach should be straight and uniform; measure downstream of riffle
- Streambed should be free of large rocks, obstructions

APPENDIX C

Turbidity Threshold Sampling Field Manual

APPENDIX D

Laboratory Procedures For Determining Suspended Sediment Concentration

APPENDIX E

Turbidimeter Instrument Log